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Viewpoint

Environmentally Sustainable Management of Used Personal Protective Equipment

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Personal protective equipment (PPE) such as face masks, gloves, goggles, gowns, and aprons are essential items to help protect individuals from exposure to pathogens and contaminants. Traditionally, PPE use against pathogens was predominantly in the hospital environment. However, the COVID-19 global pandemic necessitated that PPE is now widely used in domestic situations, leading to shortages in the supply chain, and a rapid accumulation of potentially infectious PPE in domestic solid waste streams.[1] The unprecedented domestic demand for PPE in response to the pandemic has also impacted other industries reliant on PPE, including manufacturing, construction, oil and gas energy, transportation, firefighting, and food production. Since the COVID-19 outbreak, increased production of plastic-based PPE equipment has been rapid. For example, between 2016 and 2020, the compound annual rate of increase in the global market for PPE was 6.5%, from approximately $40 Billion to $58 Billion.[2] In contrast, the World Health Organization projected that PPE supplies must increase by 40% monthly to deal effectively the COVID-19 pandemic. The essential PPE includes an estimated 89 million medical masks, 76 million pairs of medical gloves, and 1.6 million pairs of goggles.[3] The demand for PPE is not expected to decline substantially during the postpandemic period either, with an estimated compound annual growth of 20% in facial and surgical masks supply from 2020 to 2025.[2]

The sustainable management of PPE is a key challenge. The lack of a coordinated international strategy to manage the PPE production and waste lifecycle threatens to impact progress toward achieving key components of the United Nation's Sustainable Development Goals (SDGs), including SDG 3 good health and wellbeing, SDG 6 clean water and sanitation, SDG 8 decent work and economic growth, SDG 12 responsible consumption and production and SDG 13 climate action.[4] We propose product lifecycle strategies that should be integrated into solutions based on public-private partnerships.

The increase in PPE manufacture and distribution is generating an equivalent increase in the waste stream, compounded by health and environmental risks along the waste management chain, especially in countries with an underdeveloped infrastructure. China produced approximately 240 tons of medical waste daily at the peak of pandemic in Wuhan, amounting to six times higher than before the disease outbreak (Figure 1). Therefore, the local waste management agency deployed mobile incinerators in the city to dispose of the unprecedented quantities of discarded face masks, gloves, and other contaminated single-use protective gear.[1] Similar increases in discarded face masks, hand gloves, and protective goggles have been observed worldwide. For example, more than 7 million residents of Hong Kong wear single-use masks daily. There are published reports of discarded masks in the ocean and on Hong Kong's beaches and nature trails.[5]

The pandemic has impacted how solid-waste management activities are performed. The waste management and resource recycling sectors were not regarded as essential services and were placed under lock down. This disruption of routine waste management services has been documented worldwide, further exacerbated by China's earlier restrictions imposed in 2019 on the importation of "recyclable" solid waste. In response, impromptu procedures for collection and recycling of used PPE has been underway in some countries, a practice that may

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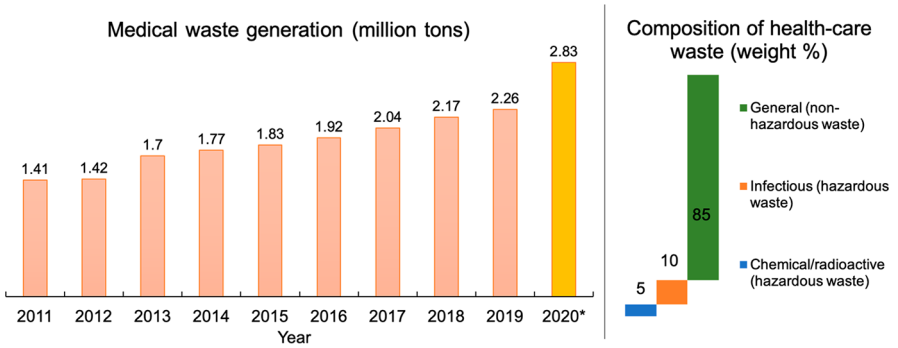

Figure 1. Medical waste generation and compositions in China. The quantity of waste is expected to increase by more than 25% in 2020.[7,11] In the U.S., there is no national database on medical waste generation because the Medical Waste Tracking Act (MWTA) of 1988 expired in 1991 and the U.S. Environmental Protection Agency has not had the authority, specifically for medical waste, since then.

present hazard due to improper decontamination.[6] Improper disposal or handling of contaminated waste can transmit viral pathogens to healthcare and recycling workers. For example, it has been estimated that up to 30% of hepatitis B, 1−3% of hepatitis C, and 0.3% of HIV rates have been communicated from patients to healthcare workers due to improper disposal of medical waste. Studies conducted in Pakistan, Greece, Brazil, Iran, and India show that higher than normal prevalence of virus infection in solid waste collectors' can be traced directly to pathogens in contaminated wastes.[7]

The United Nation's Basel Convention on the Transboundary Movement of Hazardous Wastes and their Disposal has recently urged member countries to treat waste management amid COVID-19 as an urgent and essential public service to minimize possible secondary impacts upon health and the environment. Therefore, safe and sustainable recovery and treatment of PPEs should be intensified. It is important to clarify the role of informal recyclers in developing countries, where medical waste has not been adequately regulated.

The PPE response to the COVID-19 pandemic has also impacted plastic recovery and recycling and will increase landfilling and environmental pollution. The material composition of PPE includes plastics as major constituents representing 20−25% by weight. Ultimately, if not recycled, their disposal contributes substantially to hazardous environmental pollutants such as dioxins and toxic metals. Contrary to recommendations from the World Health Organization, which encourages safe practices that reduce the volume of wastes generated and that ensure proper waste segregation at origin,[7] plastic-based PPE discarded from households is mixed with other domestic plastic wastes such as single-use plastic bags, the use of which has multiplied rapidly since grocery stores disallowed customers to bring their own bags for fear of additional virus transmission routes. Polypropylene is a common constituent of PPEs such as N-95 masks, Tyvek protective suits, gloves, and medical face shields. Polypropylene also represents a substantial proportion of the approximately 25 million tons of plastic materials that are disposed of in U.S. landfills annually, with recovery and recycling accounting for only 3% of the polypropylene plastic generated.[8]

The potential to recover polymers from mixed healthcare waste including PPE is challenging. Recycling without risking infection of individuals working as recyclers in middle- and low-income countries is limited by the low proportion (15−25%) of healthcare waste that is not contaminated. Furthermore, the low recycling rates for plastic waste worldwide and the lack of coordinated governmental policies that require minimum recycling content in new products will likely lead to an increase in virgin plastic manufacturing in the postpandemic period. The U.S. plastics manufacturing industries have requested more than $1 billion in emergency funds to deal with the extra demands attributed to COVID-19 impacts.[9] To ensure that increased plastic PPE production does not lead to increased pollution, restrictions on the emergency funds are warranted to support investments in research and development of used PPE collection, sorting, and recycling. Implementing a sustainable PPE waste management system will benefit from public-private partnerships (PPPs). In countries with economies in transition, the role of artisanal solid waste collectors and recyclers is indispensable. Developing safe and sustainable PPE management beyond the healthcare settings (hospitals and clinics) under emergency conditions is complicated because it requires a clear understanding of best practices, monitoring, and enforcement of policies and regulations. In healthcare settings, thermal, chemical, irradiative, and biological processes can be implemented locally or scaled-up in regional facilities where collection and waste transportation are possible.

Single-use PPE is not a sustainable practice, and multidisciplinary technical expertise, including biomedical sciences, environmental science, public health, materials science, and engineering is essential for tackling the PPE pollution problem. New research since the beginning of the current pandemic indicates that PPE disinfection and reuse is possible on a large scale through methods such as infusion of hydrogen peroxide vapor, ultraviolet or gamma-irradiation, ethylene oxide gasification, application of spray-on disinfectants, and infusion of base materials with antimicrobial nanoparticles.[10] Many of the disinfection methods are in the preliminary stage, and they must be calibrated to ensure that material degradation during each disinfection cycle does not compromise the primary function of PPEs to prevent penetration of pathogens and human exposure.

The circular economy principle focusing on reducing, reusing, and recycling resources should guide policy development for PPE management during and after the current pandemic. National policies should be designed to require that plastic manufacturers add minimum recycling content in new products, and product pricing should reflect environmental and health externalities. Public education campaigns to promote appropriate PPE stewardship should be integrated into policy implementation, monitoring, and enforcement. Development of infrastructure to ensure safety in informal waste collection

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and recycling in low-income countries is essential. To be sustainable, PPE management policies need be integrated into economic models that promote the adoption of green technology and alternative assessments to identify and adopt safer processes based on comprehensive materials life cycle assessments and consumer preferences.

In summary, the COVID-19 pandemic has strained solid waste management globally, while also highlighting the bottleneck supply chain challenges regarding PPE manufacture, demand-supply, use, and disposal. PPEs will continue to be in high demand, and this is the time to invest in research and development for new PPE materials that reduce waste generation, and for improved strategies for safe and sustainable management of used PPE with policy guidance at the global level.

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Notes

The authors declare no competing financial interest.

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